

Final Report

STAGNATING TURBULENT REACTING FLOWS

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prepared for

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Problem Statement

Stagnating flows of a turbulent fluid occur in many reacting flow applications. Included are turbine stagnation regions in gas turbines, several regions in diesel engines and near reattachment points in ramjets. Prior to this program, however, there was no good analytical method for prediction of heat transfer in such regions and there certainly were no adequate data for comparison with prediction.

The problem studied, both theoretically and experimentally, was the problem of stagnation point heat transfer for a flow that contained imbedded free stream turbulence. The goals were a) construction of an analytical model of the stagnation process b) comparison of the model with available experiments, c) experimentation to fill voids in the experimental data, and d) determination of voids of understanding for future work.

All goals of the program were achieved.

Summary of Results

Analytical

1. A new model of turbulent stagnating flows was constructed which matched, in a manner superior to prior theories, prior experimental results and experimental results attained under this program. These results were obtained for heat transfer under conditions of arbitrary free stream turbulence intensity and scale for low Mach number, constant mean density flows.
2. A unique discovery was made that a two parameter (intensity and scale) freestream turbulence degenerates into a one-parameter (intensity becomes related to scale) turbulence problem during the inviscid stagnation process, before flow entry into the viscous stagnation zone.

3. This flow was found to have unique properties of normal stress domination over shear stresses that required a new viscous - inviscid matching procedure to be developed.
4. Anisotropy development during the inviscid part of the stagnation process was found to not be large, justifying the use of a two equation ($k-\epsilon$) model of turbulence to be employed in the analysis.
5. The general model developed was for the variable mean and fluctuating density case, although no tests could be made against experiment because no data were available. Calculations show, however, that the effect of temperature (density) fluctuations in the freestream have an important effect upon heat transfer and experiments are required to verify this effect.

Experimental

1. In cooperation with NASA/Lewis, experiments were conducted to specifically isolate a) anisotropy development during stagnation and b) the independent effects of freestream intensity and scale on heat transfer to cylinders.
2. The experiments were matched by theory in all respects and showed small anisotropy development and clear evidence that both scale and intensity are important variables in stagnation point heat transfer.

General

The two most important summary graphs are shown in Figs. 1 and 2. In Fig. 1, comparison of theory and experiment is shown for the data of this program and some older data (Ref. [4] from Smith and Kuethe). Reynolds numbers are shown based on cylinder diameter, and only high Reynolds number results are shown since both theory and experiment show little effect of turbulence at low Reynolds number ($Re_D < 100,000$).

The solid lines and closed dots on Fig. 1 show the agreement between theory and experiment for the older data. The squares and triangles show agreement between theory and experiment for the data of this program. In general, it may be stated that the agreement is for superior to any prior theory and that the essential physics are contained in the theory.

Figure 2 shows a theoretical output of the program which does not, however, have any experimental data as back-up. Figure 2 shows an extraordinary effect of freestream turbulence levels in temperature, for fixed velocity turbulence, on stagnation point heat transfer. These calculations were done for a cooled wall case typical of turbine cooling ($T_{\text{wall}} / T_{\infty} = 0.67$). It is strongly recommended that an experimental program be initiated to verify this effect.

Publications

Refereed

1. Strahle, W. C., "Stagnation Point Flows with Freestream Turbulence - The Matching Condition," AIAA Journal, 23, 1822 (1985).
2. Strahle, W. C., Sigman, R. K. and Meyer, W. A., "Stagnating Turbulent Flows," AIAA Journal, 25, 1071 (1987).

Conference Proceedings

1. Strahle, W. C., Sigman, R. K. and Meyer, W. A., "Stagnating Turbulent Flows," AIAA Paper No. 86-0437, Reno, NV, January 1986.

Submitted to Conference (Refereed)

1. Huval, D. J., Van Fossen, G. J., Sigman, R. K. and Strahle, W. C., "Heat Transfer in Stagnating Turbulent Flows," submitted to 1st National Fluid Dynamics Conference sponsored by AIAA, ASME, SIAM.

Scientific Personnel and
Degrees Awarded

Warren C. Strahle, Principal Investigator and Regents' Professor

C. S. Murali, Graduate Research Assistant - Master of Science, 1984

William A. Meyer, Research Engineer

Robert K. Sigman, Senior Research Engineer

Danny J. Huval, Graduate Research Assistant

Note to Program Manager

This program has shown unique cooperation between Georgia Tech. and NASA/Lewis. A follow-on proposal has been submitted to continue this collaboration on the important problem of temperature fluctuation effects upon heat transfer.

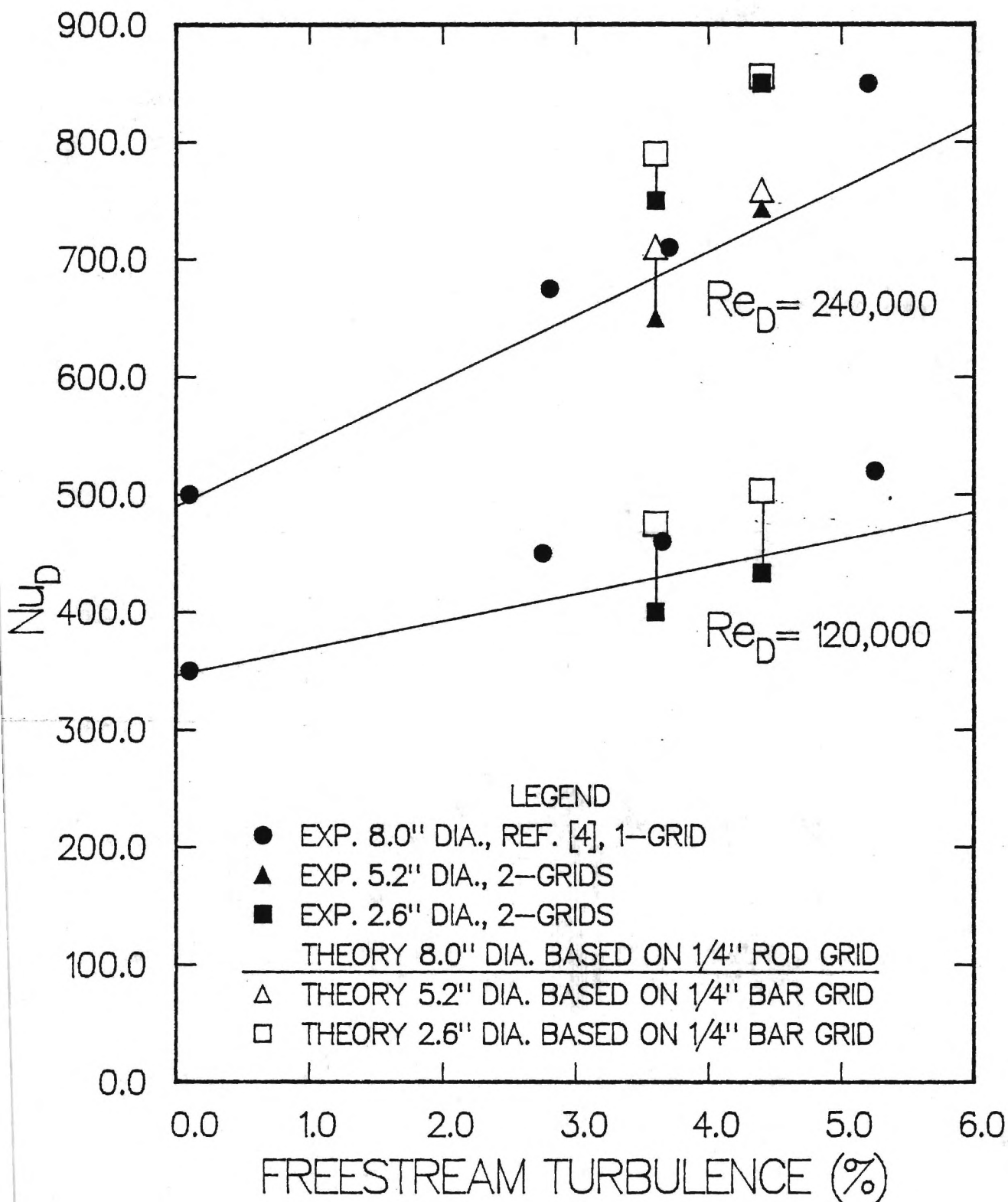


Figure 1. Nu_{ss} number for stagnating turbulent flows as a function of laminar Reynolds for cylinders as a function of freestream turbulence level and turbulence generating grid.

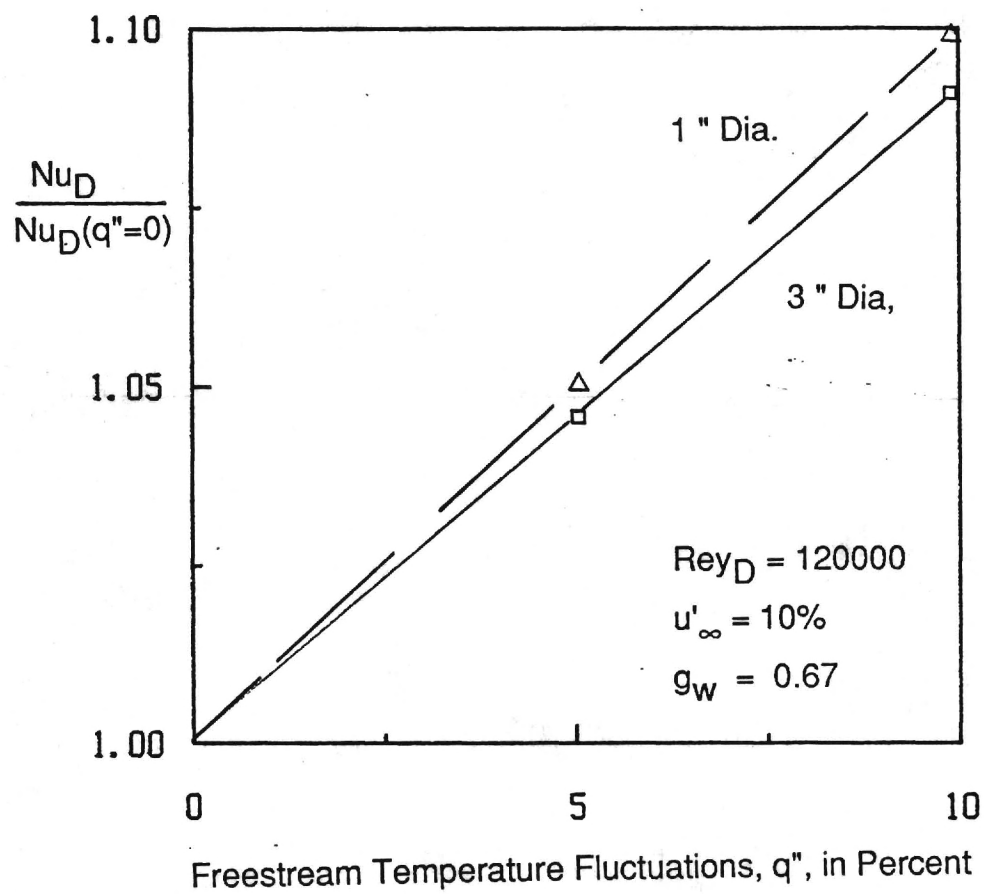


Figure 2. Rates of heat transfer to heat transfer without temperature fluctuations as a function of freestream temperature fluctuation level.